Are Different Kinds of Subjective Fears Represented Differently in the Human Brain?

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Abstract:

The brain mechanisms that generate subjective emotional experiences are still poorly understood. Fear is often considered to be represented similarly in the brain regardless of its origin. However, research suggests that subjective experience may be altered depending on the types of memory involved in the experience. For example, previous machine learning studies indicate that decoders of brain activity trained to predict situational fear (semantic information) can predict the subjective experience triggered by fear patterns (episodic information). However, the reverse does not appear to be true. This finding indicates that fear patterns probably comprise broader brain representations than those generated by situational fear. To better understand these differences, we analyzed two fMRI datasets from experiences of frightening situations (semantic memory) and schema-based fears (episodic memory). By comparing decoder performance in 214 brain regions, we identified specific representations of the two types of subjective fear. More specifically, we showed that fear schemas were predicted more accurately than situational fear in the occipital, superior temporal and ventrolateral prefrontal cortices. By better understanding the different facets of subjective fear, we hope to identify the brain structures more directly involved in the maintenance of incapacitating and long-lasting fear schemas in humans.

Keywords: subjective fear; affective neuroscience; machine learning; memory

Introduction

We still have a poor understanding of the brain mechanisms linked to the generation of subjective emotional experiences. Past research in the study of fear mainly investigated brain activity related to physiological or behavioural manifestations of fear (Taschereau-Dumouchel et al., 2022; LeDoux & Pine, 2022). However, there has been a dearth of studies delving into the subjective experience of fear itself. Recent studies have analyzed the markers of subjective fear (Zhou et al., 2021), sometimes by comparing how subjective fear is represented with respect to its physiological correlates (Taschereau-Dumouchel et al., 2020). However, it is still unclear if all subjective experiences of fear are represented similarly in the brain. Distinct memory systems, including procedural, semantic and episodic memory, may lead to different subjective experiences (LeDoux & Lau, 2020). The different systems may facilitate the development of pre-conscious meta-representations that will subsequently shape multifaceted mental schema encompassing procedural, conceptual, and/or self-oriented dimensions. Some authors have suggested that these nuanced mental constructs manifest in our consciousness through diverse modalities: anoetic, noetic, or autonoetic (Tulving, 1985). In the case of fear experiences, we could divide it into three sub-types: conditioned fear would be encoded mostly by procedural memory, situational fear by semantic memory, and fear patterns by episodic memory.

One might also expect the brain regions to represent these different fear subtypes to differ. Recent studies investigating subjective experiences revealed that brain decoders can accurately be trained to predict fear based on brain activity alone (Taschereau-Dumouchel et al., 2020; Zhou et al., 2021). Interestingly, brain decoders trained to predict situational fear (i.e., fear triggered by threatening situations) can also predict fear triggered by fear schemas (i.e., long-lasting fear of specific situations such as the fear of spiders). The reverse cannot seem to be observed. This puzzling pattern of results indicates that fear schemas may rely on brain representations that are not readily evoked by situational fear alone, possibly reflecting the “mental models” that such fear schemas evoke in the dorsolateral prefrontal cortex (LeDoux & Lau, 2020).

We posit that experiences grounded in factual knowledge, such as perceiving objective fear-inducing situations like a ravine, are primarily encoded by semantic memory (situational fear). Conversely, we propose that experiences rooted in an individual’s particular report to an object, such as an individual's history with spiders in the case of arachnophobia, would

be encoded by episodic representations (fear schemas).

Method

To study how different kinds of subjective fear are represented in the human brain, we used two open datasets of functional magnetic resonance imaging (fMRI) data collected during situational fear (Zhou et al., 2021) and schemas-based fear experience (Taschereau-Dumouchel et al., 2020). Beta images were obtained within-participants for each level of fear (6-level). Pre-processing was conducted as detailed in the original studies.

We built on our previous approach (Taschereau-Dumouchel et al., 2020) an iteratively train machine learning decoders (i.e., sparse linear regression) to predict each subjective outcome within the 214 regions of the Brainnetome atlas (Fan et al., 2016), a brain parcellation that includes both the cortical and subcortical regions. Decoders are trained in a 10-fold cross-validation procedure and performance was assessed by comparing coefficients of correlations using the Fisher method (Glen, 2020; Statistics Solutions, 2024). The significance of Z values was determined using the False Discovery rate (Significant ROIs are presented in Table 1).

Table 1: Significant ROIs of the cerebral decoder differences between fear schemas and situational fear

Lobe	Z	*p*
Frontal	3.33 – 4.00	≤ 5.96E-04
Temporal	3.23 – 6.33	≤ 1.26E-03
Parietal	3.35 – 5.59	≤ 8.19E-03
Occipital	3.20 – 6.16	≤ 1.37E-03
Subcortical Nuclei (Amygdala)	4.75	2.00E-06

Results

Our results indicate that fear schemas can be predicted more accurately than situational fear in the middle and inferior frontal gyrus; the middle and inferior temporal gyrus, the fusiform and parahippocampal gyrus, the posterior superior temporal sulcus; the superior and inferior parietal lobule, and the precuneus; the medioventral and lateral occipital cortex; and the amygdala (see Figure 1).

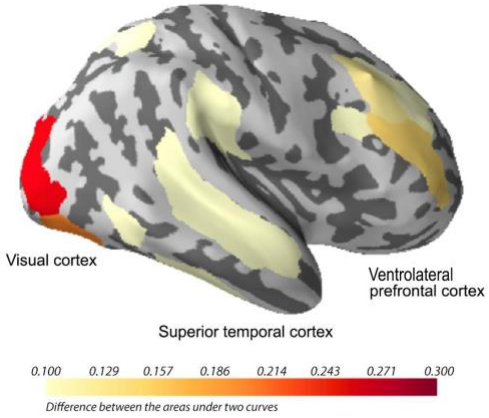

Figure 1: Cerebral decoder differences between fear schemas and situational fear

Discussion

By comparing the performance of brain decoders across different regions and the two outcomes, we pinpoint the brain regions primarily associated with the two tasks.

Subjective emotions such as fear seem to activate different cerebral regions. During schemas fear as spider image presentation, we noted that the decoder predicted with more accuracy brain regions including the visual, superior temporal, and ventrolateral prefrontal cortices.

Importantly, these results provide valuable information regarding the brain structures responsible for generating incapacitating fear schemas in individuals, related to mental health issues.

Acknowledgements

Marjorie Côté was supported by the Natural Sciences and Engineering Research Council of Canada and Dr Vincent Taschereau-Dumouchel was supported in part by the Fond de recherche du Québec - Santé and the Fondation de l'Institut universitaire en santé mentale de Montréal.

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